

2-10-11

071117
BOX 2
FOLDER 10
FILE 11

COPY

Final Report
MINE SAFETY EVALUATION
FOR
PROJECT RULISON

By R. L. Bolmer

U. S. Bureau of Mines
Denver Mining Research Center
Denver, Colorado

January 10, 1970

DISCLAIMER

Portions of this document may be illegible in electronic image products. Images are produced from the best available original document.

CONTENTS

COPY

	<u>Page</u>
Summary	1
Introduction	
Historical description	2
Mine Safety Evaluation Program	3
General setting	3
Mines in project area	4
Mine effects safety evaluation	
Mine evacuation.	6
Pre- and post-shot mine inspections.	7
Mine structural damage	8
Cameo mine.	9
Red Canon mine.	10
Busk-Ivanhoe (Carlton) tunnel	10
Carter mine	11
Monte Queen mine.	11
Ground motion	12
Conclusions	13
Appendix	
Tabulation - Effects of Rulison event on mines in the general vicinity	
Selected pre- and post-shots photographs of mines inspected for safety evaluation program	

ILLUSTRATIONS

<u>Figures</u>		<u>Follows Page</u>
1	Map of general project area showing mines and mineral plants in vicinity of Ruli- son event.	4
2-7	Photographs of structural damage in Cameo coal mine resulting from Rulison event . .	9
8-11	Photographs of structural damage in Red Canon coal mine resulting from Rulison event.	10
12-14	Photographs of damages reported at Busk- Ivanhoe (Carlton) water diversion tunnel .	11
15-16	Photographs of damages reported at Carter gold-silver mines.	11

This page intentionally left blank

MINE SAFETY EVALUATION
FOR
PROJECT RULISON

By R. L. Bolmer ^{1/}

SUMMARY

The mine safety evaluation program for Project Rulison, as carried out by the Bureau of Mines on behalf of the Atomic Energy Commission, was designed to identify, evaluate, and eliminate or control all potential hazards to mining operations in the general project area and to document the effects of the nuclear explosion on such operations.

An initial survey of the general area out to 50 miles from the emplacement well disclosed some 24 coal, oil shale, limestone, and vanadium mines which would be in active or standby status during event time and thus of concern in the safety evaluation program. Such mines were subsequently visited, and the operators were briefed on the general features of the project and its predicted effects on their operations. Recommendations for the evacuation of the mines during event time later were formulated, and pre- and post-shot inspections eventually were made of several of the closer mines where structural damage was a possibility. Pre- and post-shot photographs were taken of the most critical areas in each mine inspected. All apparent damage to the mine workings and facilities also was photographed. Operators of most fringe-area mines not inspected were contacted subsequent to the event concerning perceptible ground motion and its effect in their areas.

The post-shot inspections indicated structural damage during event time at only two mines -- the Cameo and Red Canon coal mines at 27 and 32 miles respectively from the shot point. The rather extensive damage at Cameo could reasonably be attributed to the Rulison event, while the relatively minor damage at Red Canon may or may not be. No significant damage attributable to Rulison was observed in any of the other nearby mines inspected, nor was any reported by the operators of the fringe-area mines subsequently contacted. However,

^{1/} Supervisory Mining Engineer, Denver Mining Research Center

small rock slides, isolated rock falls, and minor slumping of rock fills were observed or reported along mine access roads, especially those traversing the steeper less stable canyon slopes.

Effects of the Rulison event on the closer mines were somewhat less, and on the farther mines somewhat more, than had been expected from predicted ground motion. Better criteria obviously were needed for relating ground motion to mine damage, and modified standards were prepared from observed seismic data for any future nuclear shots in the Rulison field.

Actual mine damage from the initial nuclear explosion was experienced at observed peak ground motions of only 0.04 to 0.007 g. On the basis of this experience, any escalation in the yield of future shots would be ill-advised, particularly when the ages and physical conditions of most mines in the project area are considered.

INTRODUCTION

Historical Description

Project Rulison is a joint experiment sponsored by Austral Oil Company, the U. S. Atomic Energy Commission, and the U. S. Department of the Interior, with program management provided by CER Geonuclear Corporation, under contract to Austral. Its purpose is to study the economic and technical feasibility of using underground nuclear explosions to stimulate production of natural gas from the low-productivity gas-bearing Mesaverde formation in the Rulison field of northwestern Colorado.

The nuclear explosive for Project Rulison was detonated successfully at 3:00 p.m. plus 0.11 seconds, mountain daylight time, September 10, 1969, at a depth of 8,425.5 feet below ground level and was completely contained. Preliminary results indicate that the Rulison device behaved about as expected; i.e., with a yield of 40 (-4 to +20) kilotons. The wellhead of the emplacement well, Hayward 25-95A, is at an elevation of 8,154 feet above mean sea level and is located 1,976.31 feet east of west line and 1,813.19 feet north of south line of sec. 25, T.7 S., R.95 W., 6th PM, Garfield County, Colorado -- equivalent to geodetic coordinates of lat. 39°24'21" N. and long. 107°56'53" W.

Mine Safety Evaluation Program

This report covers the mine safety evaluation program for Project Rulison as carried out by the Bureau of Mines on behalf of the Atomic Energy Commission. Purpose of this program was to identify, evaluate, and eliminate or control all potential hazards to mining operations in the general project area and to document the effects of the nuclear explosion on such operations. The several phases of the program were carried out by the Denver Mining Research Center of the Bureau of Mines under the authorization and financial support of the Nevada Operations Office of the Atomic Energy Commission.

The subject program involved a variety of office and field investigations conducted intermittently throughout 1969. Initially, the general project area out to 50 miles from the emplacement well was surveyed for any active mines or mineral plants that might be affected by the planned nuclear experiment. All such mineral developments disclosed by the survey subsequently were visited, and the operators were briefed on the general features of the project and its predicted effects on their operations. Recommendations for the evacuation of mines in the general area during event time later were formulated, and pre- and post-shot inspections eventually were made of several of the closer mines where structural damage was considered a possibility. Supplemental post-shot inspections ultimately were required to evaluate claims for damages to other more distant mines.

GENERAL SETTING

Site of the nuclear stimulation project was the Rulison natural gas field in the Colorado River Valley of west-central Colorado. U. S. Highways 6 and 24 (Interstate Route 70) and the main line of the Denver and Rio Grande Western Railroad follow the Colorado River across the general project area between the towns of Glenwood Springs and Grand Junction. Glenwood Springs is 35 airline miles east, and Grand Junction is 40 airline miles southwest, of the site. Surface Ground Zero (SGZ) for the experiment was on the northern flanks of Battlement Mesa, some 3,000 feet above and 5 miles south of the river -- specifically at an elevation of 8,154 feet in NE/4SW/4, sec. 25, T.7 S., R.95 W., 6th PM, Garfield County, Colo. (See accompanying map of general project area.) Ground Zero for the nuclear detonation was 8,425 feet below the surface, in gas-bearing shale and sandstones of the Mesaverde formation.



FIGURE 1.

Major topographic features within the general project area include the Grand Hogback and Huntsman Hills along the northeastern and eastern edges, Battlement and Grand Mesas south of the Colorado River, and the Roan or Green River Plateau in the northwestern sector. Lands west of the Grand Hogback are in the Colorado Plateau Physiographic Province and represent a dissected plateau with strong relief. Elevations range from nearly 5,000 feet in the main drainage valleys to more than 11,000 feet on the erosional remnants of the higher mesas.

The area is on the southern flank of the Piceance Creek Basin, a major structural and sedimentary basin extending diagonally across northwestern Colorado. Sedimentary cover in the basin has an aggregate thickness of over 20,000 feet. Uplifting of the White River Plateau and Elk Mountains steeply tilted the pre-Tertiary strata along the eastern and southern margins of the basin. Similar but less severe tilting of these strata resulted from the Uncompahgre uplift on the west. The Tertiary sediments deposited contemporaneous with the structural downwarping of the basin are more nearly horizontal, exhibiting a regional dip and general thickening toward the center of the basin. The Mesaverde formation of Late Cretaceous age crops out around the interior edges of the basin, while the Tertiary Wasatch and Green River formations cover most of the project area within the basin. Green River strata overlie most of the basin north of the Colorado River, and erosional remnants of this formation are preserved below the lava capping of Battlement and Grand Mesas. The principal mineral resources of the area -- coal, natural gas, and oil shale -- are confined to the Upper Cretaceous and Tertiary strata, largely the Mesaverde and Green River formations.

MINES IN PROJECT AREA

The preliminary mineral industry survey of the Rulison project area disclosed some 24 mines and 9 mineral plants within a radius of 50 miles of SGZ, all of which would be in an active or standby status during the event time and thus of concern in any effects safety evaluation program. Relative locations of such mines and plants are shown on the map of the general project area that accompanies this report (figure 1). Inasmuch as the mineral industry plants in the general area were evaluated under the structural effects program for the project, they will not be considered further here.

By far, the largest number of active or semi-active mineral operations in the project area are coal mines. Several coal fields of

the Uinta Coal Region of eastern Utah and western Colorado -- Danforth Hills, Grand Hogback, Carbondale, Somerset, Grand Mesa, and Book Cliffs -- occur around the southern flanks of the Piceance Creek Basin. Most of these fields are 25 to 40 miles from SGZ; only a part of the Grand Hogback field is closer than 25 miles. The coal, which is confined largely to the lower part of the Mesaverde formation, has been mined in the several surrounding fields for many years. Although many of the older mines have been worked out and abandoned, a number of operations are still active in each field. Coal beds within the various fields range from horizontal to steeply pitching and contain both strong and weak caprock. Some beds are relatively free of gas, while others are moderately to extremely gassy.

More than 400 persons are employed in the 17 active coal mines in the project area. Miners at all but the smaller operations generally are unionized, and most are members of District 50 -- United Mine Workers of America.

Over the years, five experimental or demonstration mines have been opened in the so-called oil shales of the Green River formation within the project area north of the Colorado River. Such mines lie at distances of 8 to 17 miles north of SGZ, in the sector between Rulison and Grand Valley. The old Rulison mine, which is closest to SGZ, represents an early day operation and is considered abandoned. All of the others are more recent developments, largely inactive at present, but subject to periodic operation for research and experimental purposes. Typical mine development is by means of drift entries into the nearby vertical oil shale escarpments high above the valley bottoms. Horizontal room-and-pillar mining methods have been used exclusively. The wide mine openings and steep surface topography characteristics of such operations present a variety of ground control problems.

The well known Rifle Creek vanadium mine is developed in the massive Entrada and Navajo sandstones at a point some 23 miles northeast of SGZ where these older Jurassic and Triassic formations are downwarped in the prominent monocline of the Grand Hogback.

The only other active operations of any concern in the project area are two limestone quarries in the Glenwood Springs area some 35 miles from SGZ. Both are small summertime operations in the massive Leadville limestone formation of Mississippian age.

Four active sand and gravel pits and plants, 40 miles or more from SGZ, were considered in no danger from the project and thus were eliminated from further consideration under the safety evaluation program. The numerous other long-inactive and abandoned mines within the project area likewise were considered beyond all possible benefits of safety program.

Additional pertinent features of all the recently active coal, oil shale, limestone, and vanadium mining operations in the project area are included with the mine effects tabulation in the appendix of this report.

MINE EFFECTS SAFETY EVALUATION

Mine Evacuation

Recommendations for the evacuation of mines at Rulison event time were based on predictions of ground motion as well as on observed and reported conditions and age of the individual mine workings. Any damage to the mines in the area during event time, of course, would present a potential hazard to persons working in these mines. Then, too, greater caution was warranted where personal safety was involved and all the contingent factors could not be resolved. In order to provide the necessary safety factors without an undue overreaction, the aerial extent of all possible damage to mine workings and facilities was equated to the threshold of perceptible ground motion. Such threshold was assumed equivalent to a peak particle acceleration of about 0.01 gravity unit which, according to preliminary ERC predictions, would be experienced within a range of about 28 to 35 miles, depending upon the yield of the nuclear device.

It was recommended therefore, that all 8 active or standby mines within the minimum range of 28 miles from SGZ be evacuated of personnel during event time. For practical purposes, the Coal Canyon mine at 29 miles was considered with the latter group. Special conditions and considerations also warranted the evacuation of the Dutch Creek coal mines some 7 miles beyond this minimum range.

There were 7 other active mines in the 28-to-35-mile range, and another 6 such operations within 35 to 50 miles, for which evacuation was not considered necessary. Nevertheless, it was recommended that the operators of all these fringe area mines be officially alerted to the date and time of the event so as to be prepared for discretionary voluntary evacuation. No objection was raised to the official evacuation of any of the fringe area mines for acceptable reasons, technical or otherwise.

The project manager ultimately decided to evacuate all the active mines in the general area during event time. This decision was largely in response to labor union demands for lengthy paid holidays during event time. It also eliminated any preferential or discriminatory treatment between the large and small, or union and non-union, operations. Responsibility for coordinating the evacuation of all mine personnel throughout the area during event time was assigned to CER Geonuclear Corp. As far as could be determined, 100 percent evacuation was accomplished.

Pre- and Post-Shot Mine Inspections

In the absence of other criteria, the threshold of perceptible ground motion (about 28 miles from SGZ) also was used to establish the limits for pre- and post-shot inspections of possible mine structural damage.

Pre-shot inspections of 7 active or standby mines within the 28-mile range were made during the period August 21 to September 3, 1969. Post-shot inspections of these same mines were made as soon as possible after the event, or during the period September 11-17, 1969. Only two of the active or standby mines originally disclosed within this maximum effects range were not inspected. No inspections of the Mobil oil shale mine were attempted because of the security restrictions insisted on by the operator. The planned inspections of the Coal Canyon strip mine proved neither warranted nor feasible inasmuch as the operations terminated before event time and the access road had since been washed out by flash floods.

A non-scheduled post-shot inspection of the Red Canon coal mine at 32 miles from SGZ was made September 13, 1969, upon receipt of a damage report from the operator. At the request of the Project Rulison Claims Office, special post-shot damage investigations also were made of the Busk-Ivanhoe (Carlton) water tunnel on October 7th and of the Carter gold mines on November 10th and 11th. Both of these semi-active operations were well outside the general project area -- the tunnel some 80 miles east, and the mines some 93 miles southeast, of SGZ. Special mine damage inspection reports were prepared in four cases where claims for damages resulting from the Rulison event were investigated.

The various pre- and post-shot examinations within the general project area were made with one or more of the Bureau's Coal Mine

Inspectors -- principally Vernon A. Bowling of Grand Junction. Oscar T. Rice, Deputy State Coal Mine Inspector from Paonia, assisted in the examination of the Roadside and Cameo coal mines. Fred L. Smith of Denver, a consulting mining engineer engaged by CER Geonuclear at the request of the operators, also participated in the examinations of these latter two mines. A representative of the operator was present during all pre- and post-shot examinations except those at the Roadside coal mine and the inactive Bureau of Mines oil shale mine. Pre- and post-shot photographs were taken of the most critical areas in each mine inspected. All apparent damage to the mine workings and facilities from the event also were photographed. Operators of most of the fringe-area mines not formally examined were contacted subsequent to the Rulison event concerning the perceptible ground motion and its effect, if any, in their general areas.

Mine Structural Damage

The post-shot inspections indicated structural damage during event time at only two mines -- the Cameo and Red Canon coal mines at 27 and 32 miles respectively from SGZ. The rather extensive damage at Cameo can reasonably be attributed to the Rulison event, while the relatively minor damage at Red Canon may or may not be. There was no evidence of any new roof falls in the Bureau of Mines oil shale mine (10 miles from SGZ) where several large falls have occurred in the past and minor falls occur periodically. A small chunk of coal about 6 inches in diameter dropped from the roof of the new lower level of the Nu-Gap coal mine (20 miles from SGZ) but caused no damage. An isolated timber prop supporting power cables along the main entry of the Roadside coal mine (27 miles from SGZ) also was toppled during event time, but such damage was readily remedied and could hardly be rated compensable. No damage attributable to the Rulison event was observed in any of the other nearby mines examined, nor was any reported by the operators of the fringe-area mines subsequently contacted. However, small rock slides, isolated rock falls, and minor slumping of rock fills were observed or reported along mine access roads, particularly those traversing the steeper and less stable canyon slopes.

Other pertinent information from the post-shot inspections of the nearby mines and from the operators of the fringe-area mines not inspected is summarized in tabular form in the appendix of this report. Selected pre- and post-shot photographs of the more critical sections of the mines inspected also are included there. Photographs of the confirmed structural damages in the Cameo and Red Canon mines,

and of the reported but unsubstantiated damages in other mines, are included with the brief descriptions of such damages given below.

Cameo mine The coal in the Cameo mine is overlain by about a foot of carbonaceous mudstone, some two feet of soft jointed sandstone, and a rider seam of coal a few feet thick. This roof strata, particularly the mudstone caprock, is unstable and subject to frequent failures in sections of the mine. In the shallower workings near the outcrop, the roof strata contains prominent vertical fractures which begin to open as soon as the coal is mined. Subsequent strata separations along bedding planes permit the roof to sag and eventually to collapse, often in spite of the normal mine supports.

Most of the mine roof spans are reinforced by 3-foot roof bolts anchored in the jointed sandstone above the caprock. Wooden cross-bars, held against the caprock by both roof bolts and timber posts, generally are installed along the main entries. In many places, the caprock breaks into small plates which drop out and reduce tension on the roof bolts. Many bolt anchors also are prone to slip. As a result, the reinforced roof span begins to sag, initiating new tension cracks and bedding separations and insuring ultimate roof failure unless timber props are installed.

Locally near the coal outcrop, the original roof strata was eroded away by ancient streams and later replaced by loosely cemented gravel and boulders. Such material generally caves to a height of several feet above any coal mined below it, necessitating extensive cribbing, lagging, and other timber support.

Most of the structural damage disclosed by the post-shot inspection and attributed to the Rulison event, was confined to working areas under shallow cover, close to the outcrop -- specifically the 1st Southwest section and the Nos. 1 and 2 Outside entries. In these areas of poor to bad roof, new cracks in the caprock were formed, and some of the old existing cracks were enlarged. (See figures 2 to 5.) A small roof fall also occurred along one entry, and the resulting separation of the roof strata adjacent to this fall placed excessive weight on several successive timber sets in the entry. (See figures 6 and 7.)

Necessary repairs to this section of the mine, as determined by the consultant engaged at the request of the operator, involved the removal of 4 damaged timber sets, the cleanup of some 9 cubic yards of fallen rock, and the installation of 25 new timber sets along 150 feet

Cameo Mine
9/11-12/69



Fig. 2 - New crack in caprock
($\frac{3}{8}$ inch wide by 30
feet long) of the No.
2 Outside entry at No.
4 Crosscut.

Fig. 3 - New crack in caprock
($\frac{1}{2}$ inch wide by 40
feet long) of No. 1
Southwest entry out-
by No. 1 Outside entry.



Fig. 4 - New crack in caprock
(1/4 inch wide by
150 feet long) in No.
2 Outside entry at
1st Intersection in-
by Main Air Return.

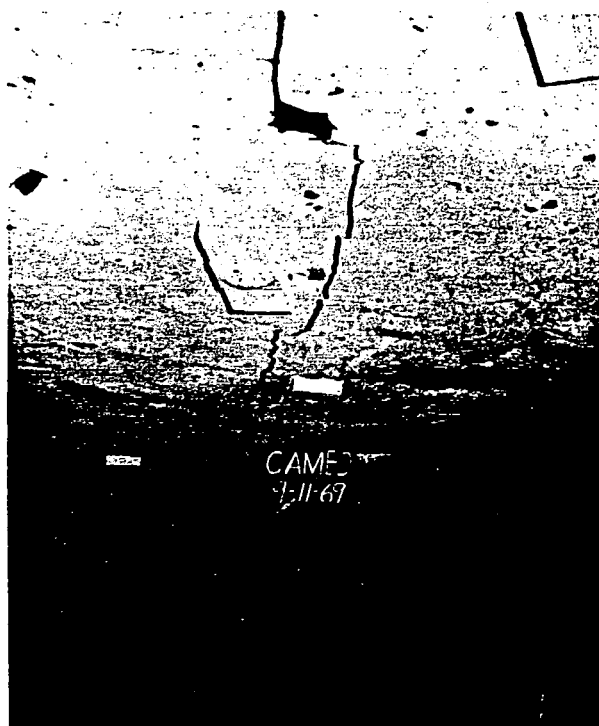
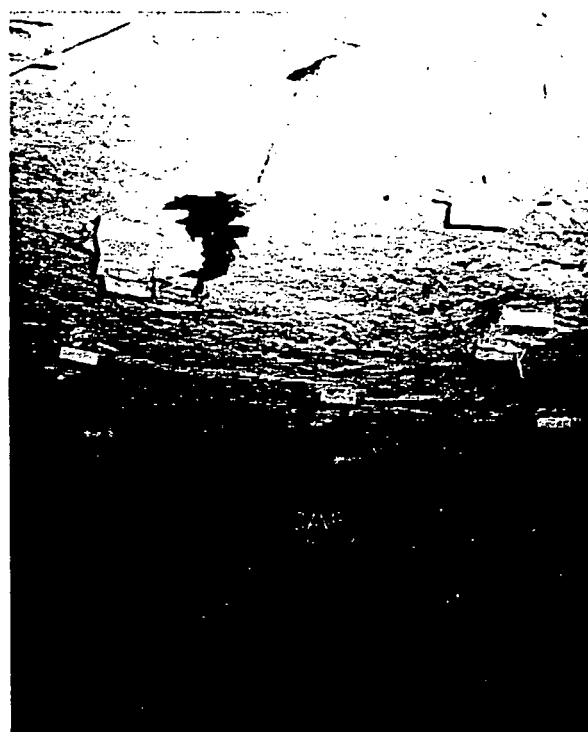


Fig. 5 - New crack in caprock
(3/8 to 1/2 inch wide)
along No. 2 Outside entry
between 1st and 2nd
Intersections.



Fig. 6 - New Cave-in (16'x4'x2') showing roof strata separation (note film box and roof cane) in No. 2 Outside entry, 40 feet outby face.



Fig. 7 - Roof fall (+ 3 cubic yards) and sagging cross bar in No. 2 Outside entry, 40 feet outby face.

of entry -- all of which was estimated to cost about \$1,000. The operator subsequently submitted a damage claim for cleaning up the fallen rock and systematically timbering 1,000 feet of entry with 200 timber sets plus 2 intersections with 6 sets -- all at a total cost, including attorney fees, of \$8,897. To date, no reconciliation between the consultants' determination and the operator's claim has been attempted.

The development of numerous small new cracks in the caprock and the enlargements of existing cracks also were noted in the "A" Raise section of the mine. This latter section is more than a mile from the coal outcrop and has a relatively good roof, but lies below a slender erosional remnant of rock that extends some 1,000 feet above the general ground level. The damage here was not considered severe enough to require additional timber supports and therefore, probably is not compensable. The operator makes mention of this damage, but does not claim compensation for it. Two other sections of the mine -- one with relatively good roof conditions (2nd East pannel) and the other with very poor conditions (3 West haulage entry) -- suffered no observable damage from the event.

Red Canon mine The shale roof in the Red Canon coal mine is structurally quite stable and has stood for years supported only by timber props. However, even this roof stone begins to sluff in time, and relatively small thin slabs periodically drop from the roof throughout the mine. Such rock is often left where it falls, but may be stacked by hand behind the timber props along the sides of the travel and haulageways.

The special post-shot inspection of this mine revealed that an aggregate of about 1/2 cubic yard of the shale caprock had recently fallen from the roof in four isolated sections of the workings. (See figures 8 to 11.) The most serious fall occurred midway along the inclined return airway where a thin slab, about 4 feet by 2 1/2 feet in area, had dropped onto the electrical power cables serving the mine. In dropping, this slab tore loose the power cables from their insulated hangers on two adjoining timber props. The cleanup of all the recently fallen rock and the rehangng of the power cables were estimated to require about 1/2 man-shift at a cost of about \$25.

Busk-Ivanhoe This 9,400-foot tunnel was driven through the
(Carlton) tunnel Precambrian granite core of the Continental Divide before the turn of the century. Originally a railroad tunnel, it is now used exclusively for water diversion. The tunnel has a long history of cave-ins and is heavily timbered throughout



Fig. 8 - Thin slab of caprock down on power cables
in return airway just east of incline shaft.



Fig. 9 - Caved caprock (darker material on top of old cave
and under lamp) in level entry just east of incline shaft.

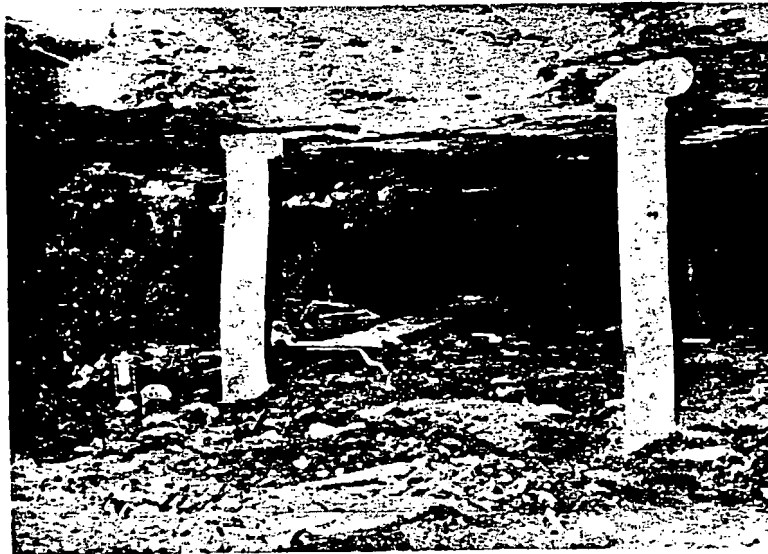


Fig. 10 - Caved caprock (by lamp and on shaker pan) in level entry east of incline shaft.



Fig. 11 - Caved caprock (darker material in foreground and below lamp) in old room driven up pitch from level entry east of inclined shaft.

its length. Most of the original tunnel supports have long since deteriorated, but only part of these have been repaired or replaced.

A major cave-in of about 130 cubic yards of rock and timber at 4,200 feet from the east portal, plus minor rock and timber falls at four other locations, was reported to have occurred sometime between September 9th and 15th. (See figures 12 to 14.) Investigations indicated that the major cave-in could have coincided with the Rulison event, but that the minor rock and timber falls may not have. No ground motion was felt in the immediate area, and such motion as could be projected for the area probably was too low to have caused the damage. Any consideration of the past history of the tunnel and its present physical condition leaves little doubt that the cave-in would have occurred sooner or later, irregardless of the Rulison event.

Carter mine Damages to the Carter and two other contiguous gold mines, consisting of caved adit portals in alluvium and caved drifts below old shrinkage stopes, also were reported as resulting from the Rulison event. (See figures 15 and 16.) An inspection revealed nothing conclusive that would tie this damage to Rulison. About all that could be determined was that it probably was of recent origin. The sections of the mines found damaged were those most susceptible to natural cave-ins. Considering the age of the workings, the conditions of the old timbers, and the altered nature of the Precambrian granite and schist wall rock, such cave-ins would be expected to occur periodically at any time. It was concluded that the damages reported were of natural origin and not related to the Rulison event.

Monte Queen mine The operator of this silver mine, some 102 miles south of SGZ, near Lake City, reported that about 25 tons of loose rock was dislodged from a working face during event time. An inspection was not made inasmuch as no compensable damages to mine workings or machinery were claimed. The mine workings reportedly are along an "active" fault-fissure in the Eureka rhyolite (a Tertiary volcanic flow). As far as can be determined, there are no fault structures extending from the general project area into the Lake City area, and it is unlikely that sufficient ground motion was experienced here to have caused the reported rock fall.



Fig. 12 - West end of major
cave-in at 4200 feet.



Fig. 13 - East end of major cave-in
at 4200 feet.



Fig. 14 - Disintegrated wall plate, toppled
post, and sagged arch segment of
old tunnel set at 4055 feet.



Fig. 15 - Caved portal of No. 2
level of Golden Islet
mine.



Fig. 16 - Caved portal of No. 3 level of
Golden Islet mine.

GROUND MOTION

A comparison of predicted and observed ground motions at several seismic recording stations near certain mines in the project area, as reported by Environmental Research Corp. in NVO-1163-180 and -197, is tabulated below. The actual yield of the Rulison device has not been announced, but for comparison purposes, is assumed to be the design yield of 40 kilotons.

<u>Miles and direction from SGZ</u>	<u>Seismic station w/nearby mines</u>	<u>Peak acceleration, g (Predicted)(Observed)</u>	
9 N	Mobil/Mobil and USBM oil shale mines	0.135	0.056
21 NE	Harvey Gap/Nu-Gap coal and Rifle vanadium mines	0.025	0.031
27 SW	Cameo/Cameo and Roadside coal mines	0.016	0.038
34 S	Cedaredge/Red Canon, Top and Green Valley coal mines	0.009	0.007
35 E	Glenwood/Four-Mile coal mine, two limestone quarries	0.008	0.005
41 SE	Paonia/King, Somerset, Bear, Black Beauty and Hawk's Nest coal mines	0.006	0.011
44 N	Meeker/Rineau coal mine	0.005	0.004

The ground motions recorded at the majority of the seismic stations throughout the area were somewhat higher than had been predicted. However, both higher and lower magnitudes were observed at the few stations strategically located with respect to the mines in the area. At the Cameo mine, where significant damage occurred, the observed peak particle acceleration of 0.0375 g was 250 percent of the predicted peak amplitude. Minor damage occurred in the Red Canon mine at a peak acceleration of only 0.007 g -- a mere 78 percent of the predicted value.

In contrast to the predictions, actual ground motions did not attenuate proportionately with distance in all sectors of the project area. Although not fully understood, this discrepancy probably is the result of other physical factors that vary from sector to sector, such as rock type, structural deformities, surface topography, and so on.

CONCLUSIONS

Effects of the Rulison event on the closer mines were somewhat less, and on the farther mines somewhat more, than had been expected from the predicted ground motion. Better criteria obviously was needed for relating ground motion to mine damage, particularly in the near perceptible range and for old deteriorated workings in bedded strata having wide roof spans and poor-to-bad roof conditions -- such as apply to most mines in the project area.

A cursory examination of the observed seismic data indicates that the ground motion from the event is not a function of distance alone, but probably is affected by a variety of other variables. Consequently, a greater safety factor for the limits of both mine evacuation and potential structural damage should be applied until the parameters of all such variables are known. Use of the threshold of perceptible ground motion for the limits of both structural damage and personnel evacuation still appears justified. However, a threshold value of 0.005 g for the highest predictable yield probably would be more appropriate, considering the multitude of unknown factors.

Actual mine damage was experienced from ground motions of about 0.04 to 0.007 g, at distances of 27 and 32 miles respectively from SGZ. On this basis, it could be reasoned that the yield of the Rulison nuclear device on September 10th already was too great. Damages in the range of those discussed here certainly could be expected from any future shots of the same yield. The cumulative effect of a multitude of shots in this range also may increase the overall damage potential.

There is no doubt that future shots of greater yield would enlarge the radius of mine damage, perhaps significantly. It also is quite likely that some of the closer mines which survived the initial shot unharmed would begin to show structural damage. Actually, some of these closer mines were believed on the brink of damage from the initial shot, and it is possible that not all of the structural damage from the initial shot was immediately evident. Such effects as hidden fractures and strata separations may not show up for long periods.

Natural gas and atomic energy are the principal competitors of coal in the total energy field. Even if it were not their own mines that were being shaken up, opposition from the coal mine operators and unions would be expected to increase in proportion to the number and size of the nuclear explosions that are attempted.

A P P E N D I X

EFFECTS OF RULISON EVENT ON MINES IN VICINITY

Miles and direction from SGZ	Mine	General Features	Ground Motion	Observed or reported damage/other comments
9 N	MOBIL oil shale	Experimental room-and-pillar mining (1964-68). High, wide rooms with poor to fair roof.	Strong	No damage to mine. Surface effects same as USBM mine below.
10 N	USBM oil shale	Experimental room-and-pillar mining (1945-56). High, wide rooms with poor to fair roof.	Strong	No damage to mine. Rock slide and slump cracks on access road. Small rocks dropped from cliff above mine yard. Slide raised dust east of mine.
15 NNW	UNION oil shale	Experimental room-and-pillar mining (1956-59). High, wide rooms with fair to good roof.	Moderate to strong	No damage to mine. Small rock falls along access road.
17 NNW	COLONY oil shale	Experimental room-and-pillar mining (1964-68). High, wide rooms with fair to good roof.	Moderate to strong	No damage to mine. Small slide on mine road. Rocks fell from canyon walls and dust raised. Autos rocked.
20 NE	NU-GAP coal	Small truck mine being developed from outcrop of steeply pitching coal seam in Grand Hogback.	Moderate	No damage to mine. Chunk of coal dropped from roof. Loose soil ran down surface cut at portal. Power cables swayed.
23 NE	RIFLE vanadium	Open room-and-pillar retreat mining (pulling pillars) in pitching massive sandstone.	Moderate	No damage to mine. No increase in radioactivity. Extensometers showed no permanent strata separation. Power cables swayed

EFFECTS OF RULISON EVENT ON MINES IN VICINITY

Miles and direction from SGZ	Mine	General Features	Ground Motion	Observed or reported damage/other comments
27 SW	CAMEO coal	Open room-and-pillar mining in flatly-pitching seam with generally poor to bad roof. New workings under shallow cover, near outcrop.	Moderate to strong	Small roof fall with strata separation, damaged timber sets, and extensive cracking of caprock. New workings near surface showed most damage.
27 SW	ROADSIDE coal	Mining same seam as Cameo but with less cover and better roof. Air intake and return badly deteriorated.	Moderate to strong	No damage except for toppled timber prop in main entry. Large rim-rock boulder reportedly dislodged southwest of mine.
29 SW	COAL CANYON strip	Auger mining in coal outcrop below high bank with loose rock above.	---	Not inspected and no report as mine closed and road washed out prior to event time.
32 S	RED CANON coal	Small truck mine in pitching seam with fairly stable roof. Portal and tipple sound.	Slight	Small roof falls aggregating about 1/2 cu. yd. in 4 areas of mine. Loose tin on roof of tipple rattled.
32 S	GREEN VALLEY coal	Small truck mine in pitching seam with only fair roof. Portal sound.	Not perceptible	No damage to mine or surface plant.
33 S	TOP coal	Small truck mine in pitching seam with fair to good roof. Portal sound.	Not perceptible	No damage to mine or surface plant. Table in nearby home rattled.

EFFECTS OF RULISON EVENT ON MINES IN VICINITY

Miles and direction from SGZ	Mine	General Features	Ground Motion	Observed or reported damage/other comments
34 WSW	MCGINLEY coal	Small truck mine in narrow canyon with loose rim-rocks.	Not perceptible	No damage to mine or surface facilities. Barely perceptible at home in Fruita.
34 E	FOUR-MILE coal	Small truck mine in steeply-pitching seam in hogback. Portal sound.	---	No report.
35 ESE	DUTCH CREEK coal	Two large adjoining mines on pitching seam--both extremely gassy and subject to ground "bumps".	Not perceptible	No damage to mine and no excessive gas released.
35 ENE	BASIC CHEMICAL lime	Small limestone quarry worked in summer season with contract crew.	---	No report. Barely perceptible in Glenwood Springs. Some cars rocked.
35 ENE	GLENWOOD lime	Small limestone quarry worked in summer season with contract crew.	---	No report. Barely perceptible in Glenwood Springs. Some cars rocked.
40 SE	KING coal	Gassy mine on flatly-pitching seam with poor roof. Portal and tipple sound.	Barely percept.	No damage in mine. Surface tipple rattled.
41 SE	SOMERSET coal	Large slope mine on 2 seams, 40 ft. apart--both gassy with bad roof.	Barely percept.	No damage to mine or plant. Coin balanced on mine rail not disturbed.

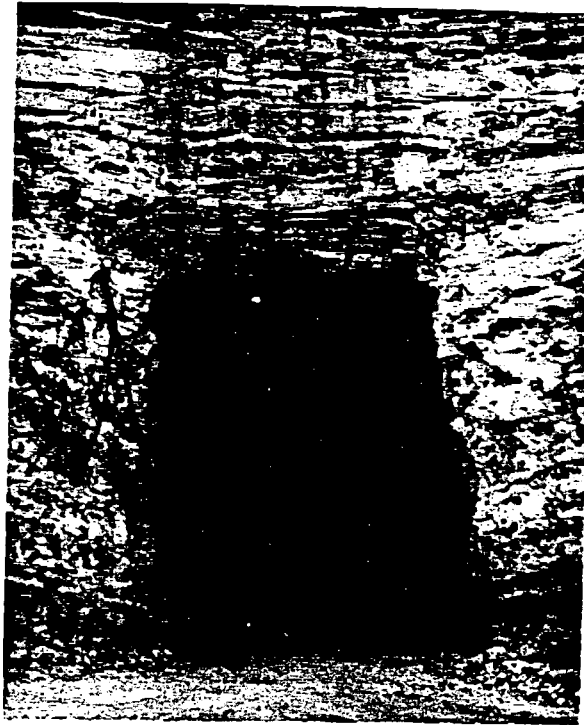
EFFECTS OF RULISON EVENT ON MINES IN VICINITY

Miles and direction from SGZ	Mine	General Features	Ground Motion	Observed or reported damage/other comments
42 SE	BEAR coal	Medium-size gassy drift mine with poor roof, sound portal.	Barely percept.	No damage to mine.
43 SE	BLACK BEAUTY coal	Small slope mine. Flimsy tippie on steep slope with loose rocks.	Not perceptible	No damage to mine and no rock falls from slope above tippie.
43 SE	HAWK'S NEST coal	Small mine on flatly-pitching seam with average roof. Old but sound tippie on slope with loose rocks.	Not perceptible	No damage to mine. No rock dust shaken ont previously cleaned conveyor belt in main entry. Table in nearby home rattled slightly.
49 N	RINEAU coal	Small drift mine with average roof, sound portal and tippie.	Not perceptible	No mine damage and no rock falls on surfac Bottles rattled in Meeker Hotel.
64 NW	WHITE RIVER coal	Small slope mine with average roof, some 5 miles SE of Rangely.	Not perceptible	No damage to mine. Some persons in Rangely reportedly felt tremor.
79 E	BUSK-IVANHOE water tunnel	9400-ft bore through granite core of Continental Divide west of Leadville.	Not perceptible	Major cave-in reported, but not substantiated, as resulting from Rulison event.
93 SE	CARTER gold	Several old contiguous mines in Gold Brick District ENE of Gunnison.	Not perceptible	Caved adit portals and level drifts reported, but not substantiated, as caused by event.

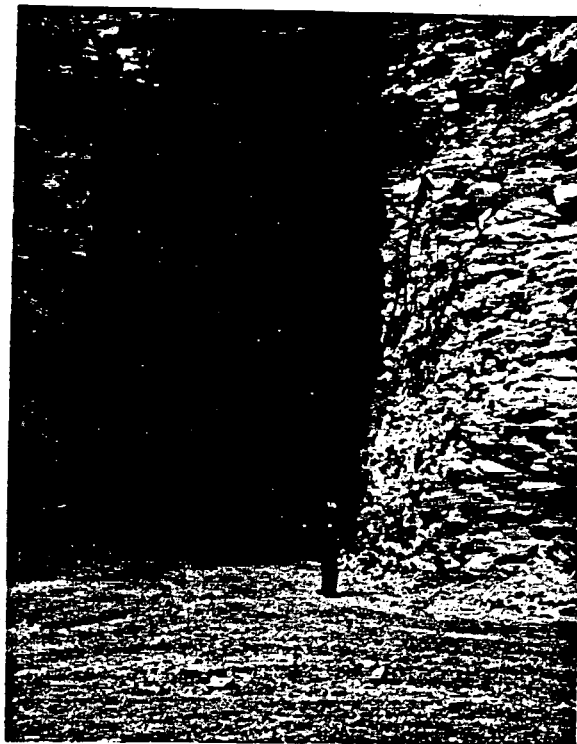
EFFECTS OF RULISON EVENT ON MINES IN VICINITY

Miles and direction from SGZ	Mine	General Features	Ground Motion	Observed or reported damage/other comments
102 SSE	MONTE QUEEN silver	Mine, about 1 mile S of Lake City, reported on "active" fault-fissure in Eureka rhyolite.	Barely percept.	25 tons rock reported dislodged from working face during event time. Not investigated, but considered unlikely on basis of insufficient ground motion.

Mobil oil shale mine
Pre- and post shot photos

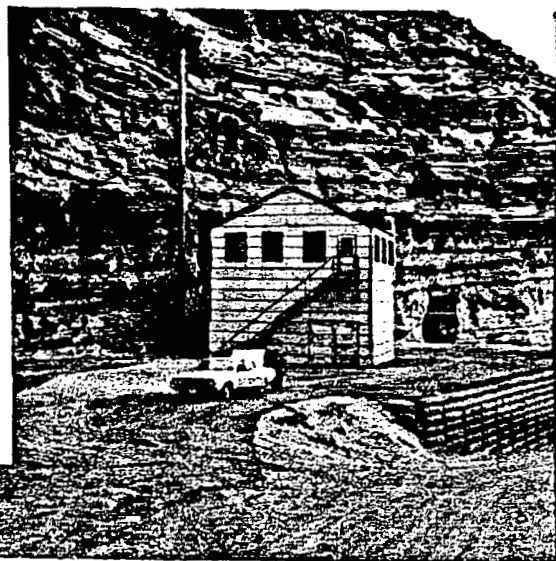
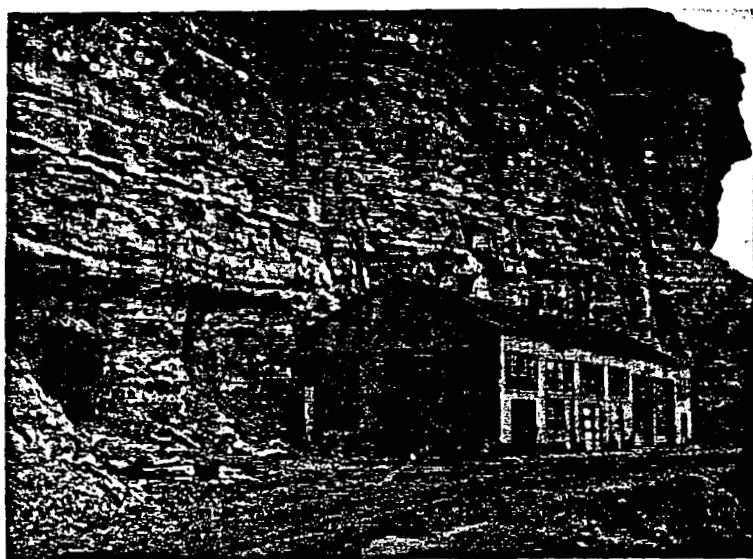
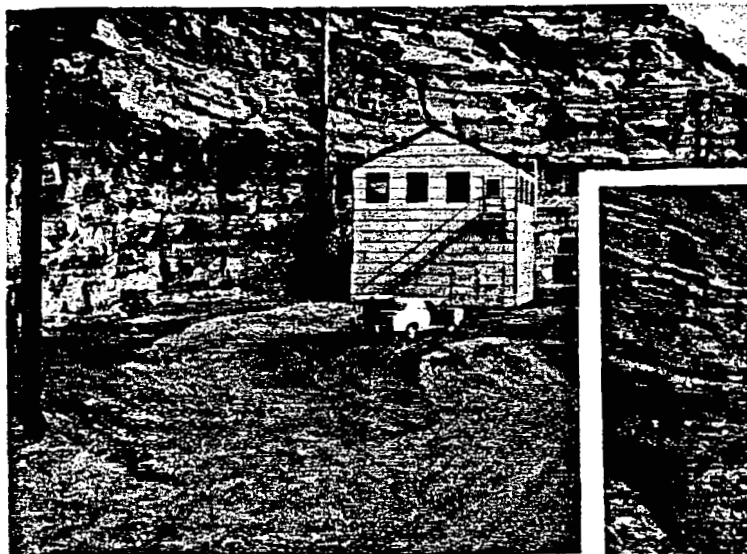


Portal of adit
to Mobil mine
8/27/69



Portal of adit
to Mobil mine
9/15/69

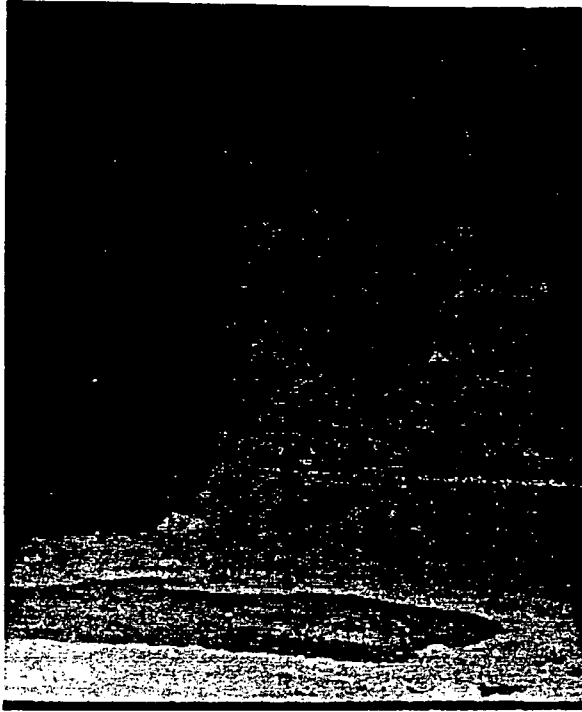
8/27/69



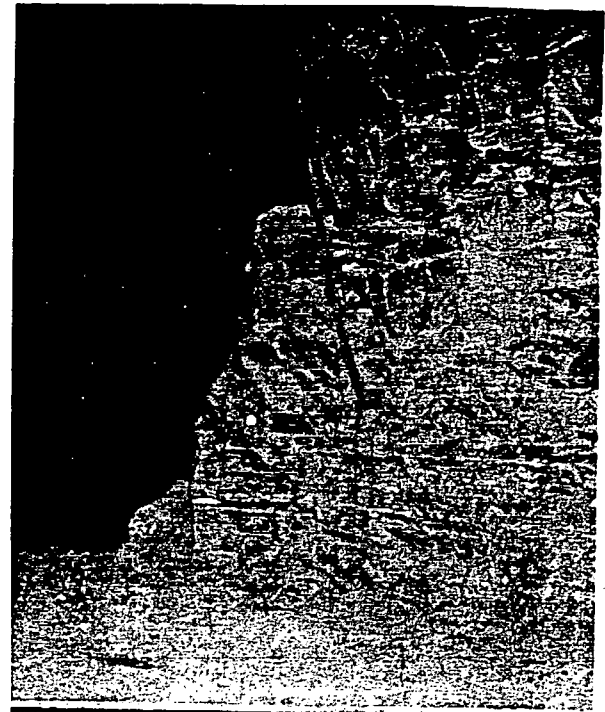
9/15/69

Mine yard around old office and shop buildings

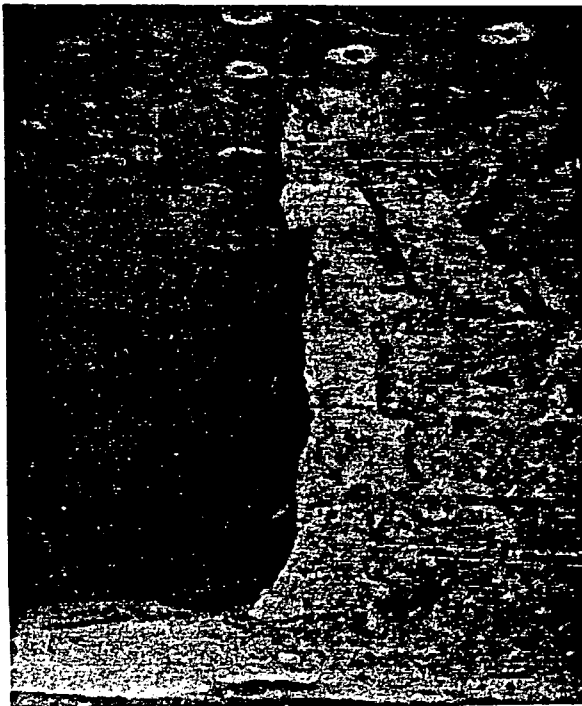
8/27/69



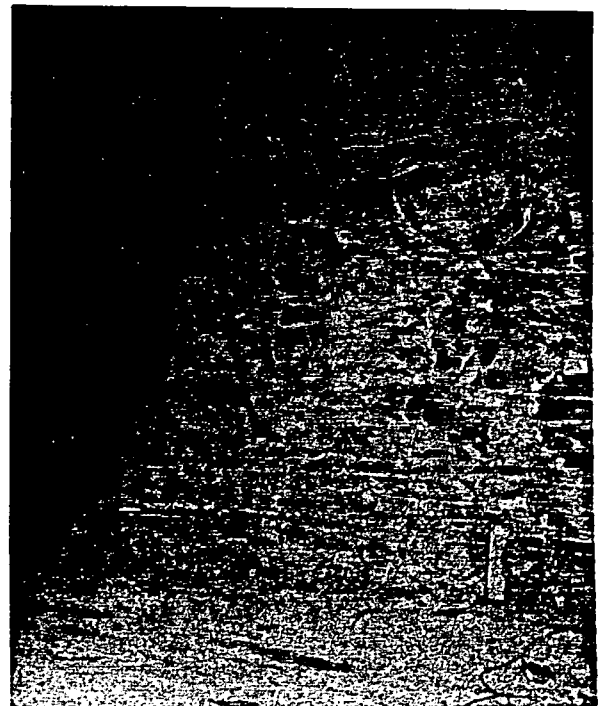
8/27/69



Fractured corners of 30-ft pillars midway along Able haulageway



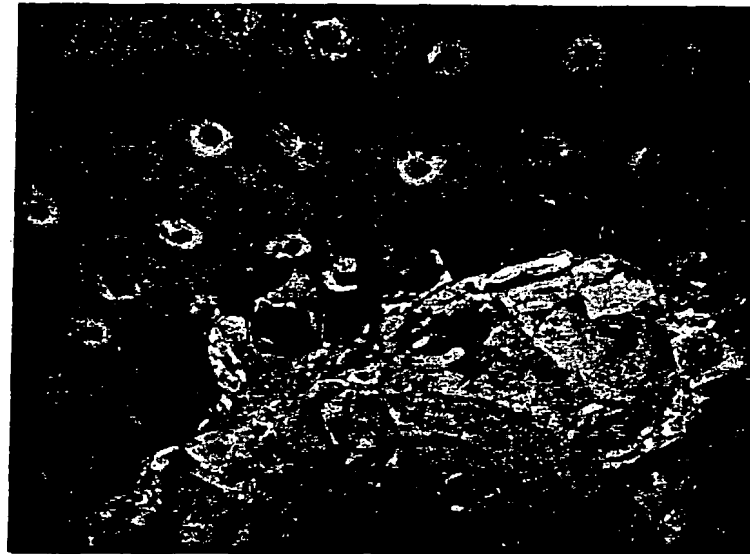
9/15/69



9/15/69



8/27/69



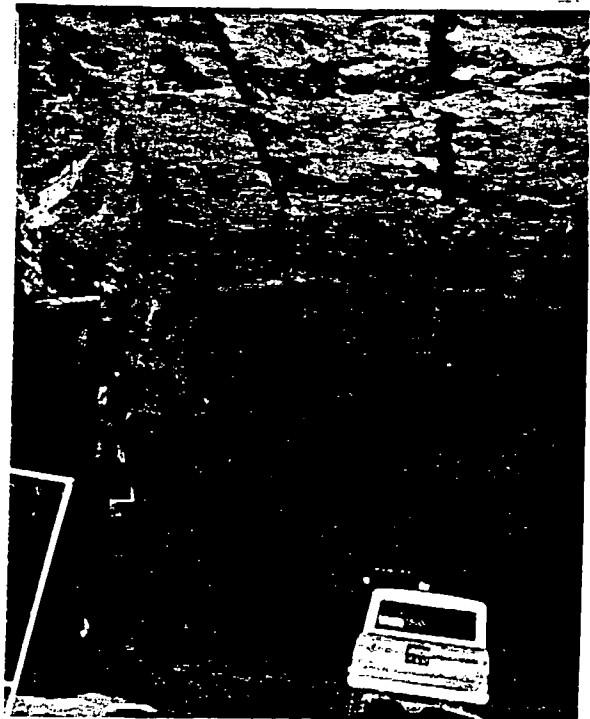
9/15/69

Rocks hanging from roof bolts at
edge of second major roof-fall area



8/28/69

Roof of haulage adit



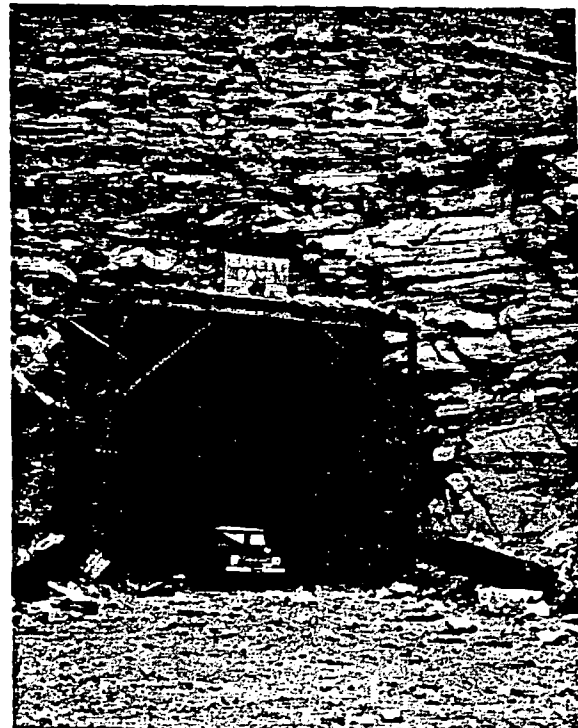
9/16/69

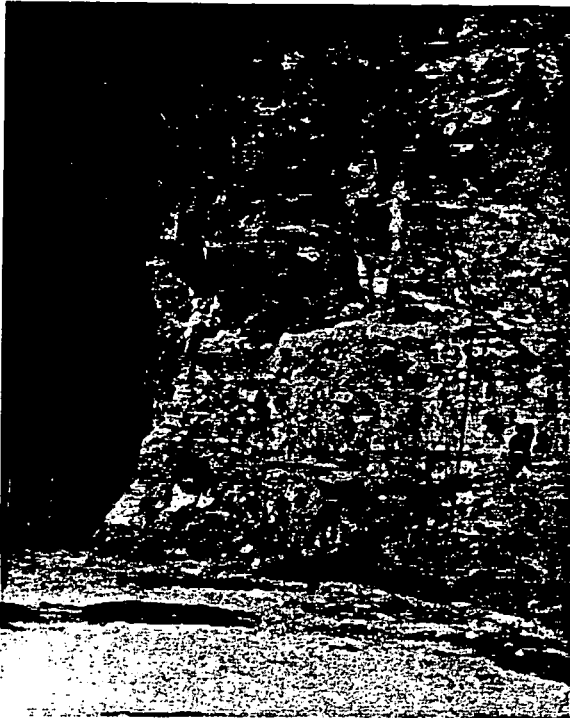
9/16/69



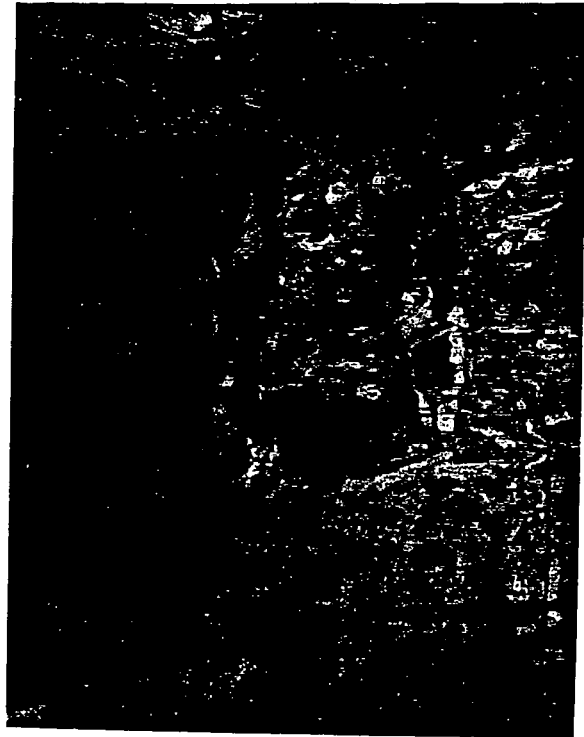
8/28/69

Portal of haulage adit

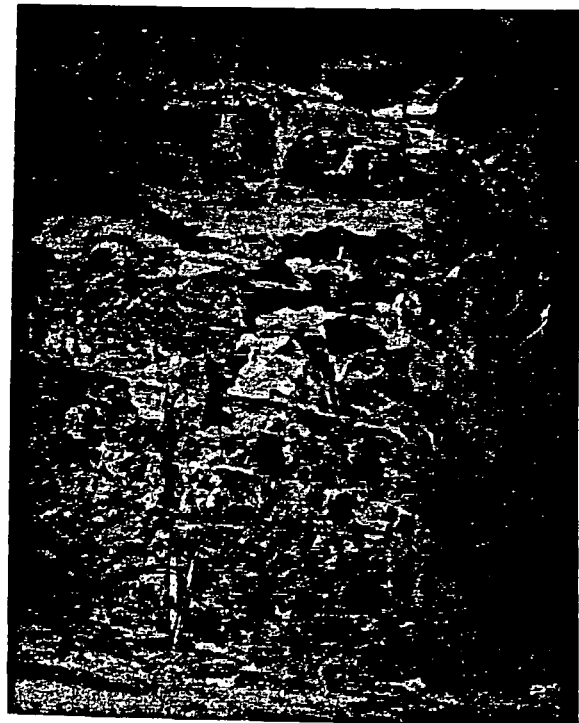




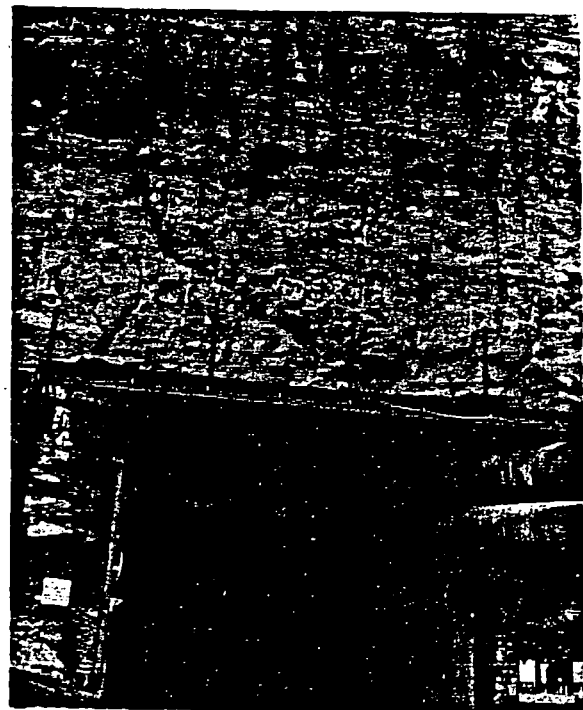
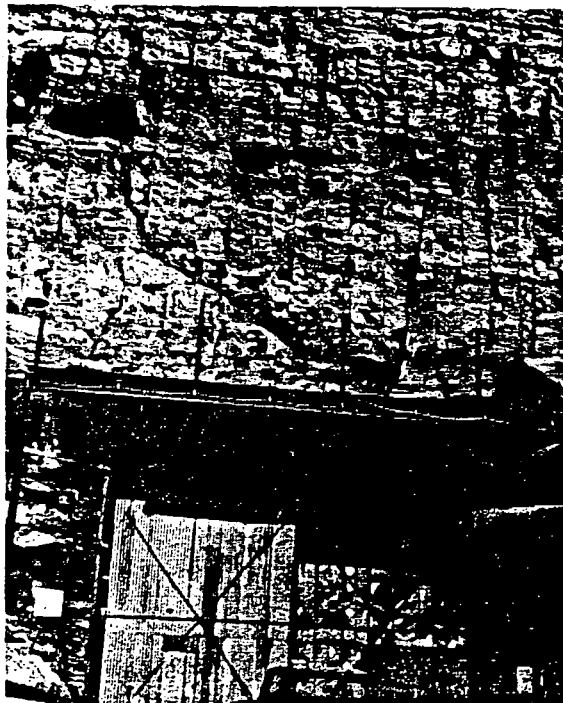
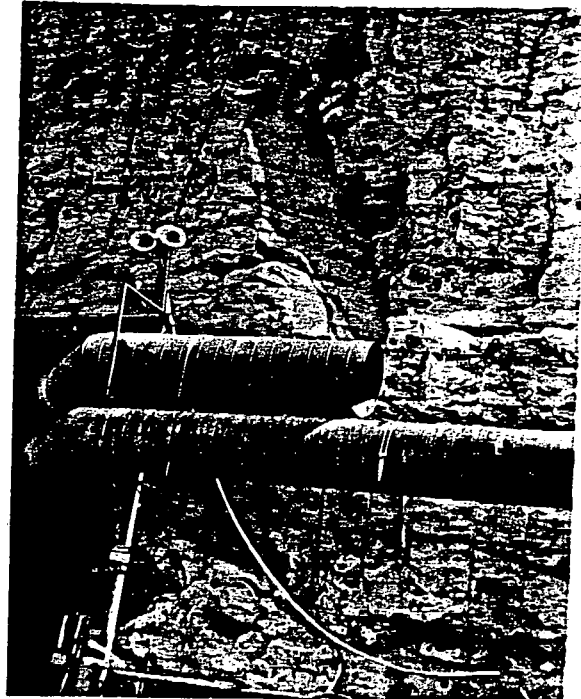
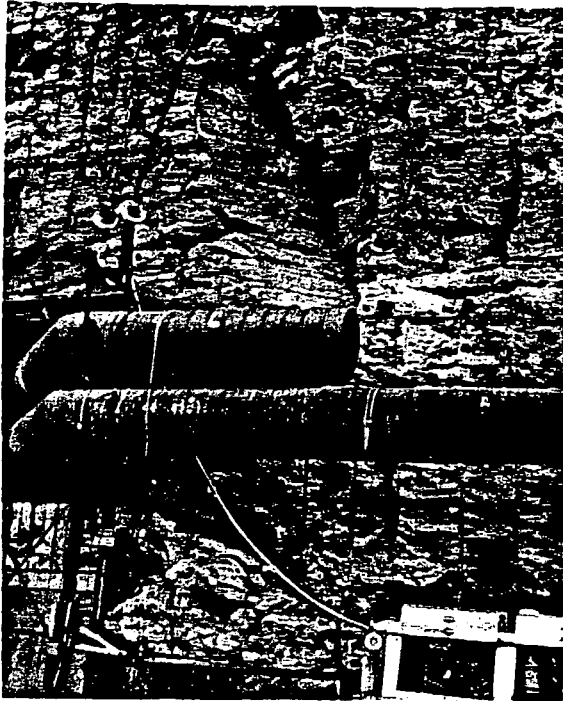
8/28/69



9/16/69



Walls of 30-ft. pillar at end of haulage adit



8/28/69

9/17/69

Vertical cut in oil shale strata above adit portal



9/17/69

Caved section of vertical
cut alongside mine yard



8/21/69

9/17/69



8/21/69

Intersection of Adit and Room 1

8/21/69



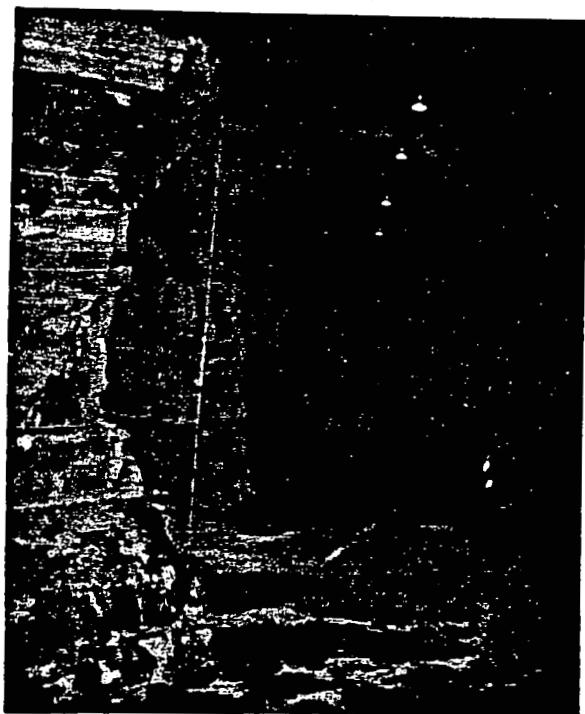
8/21/69

Room 4 (52'W by 60'H)

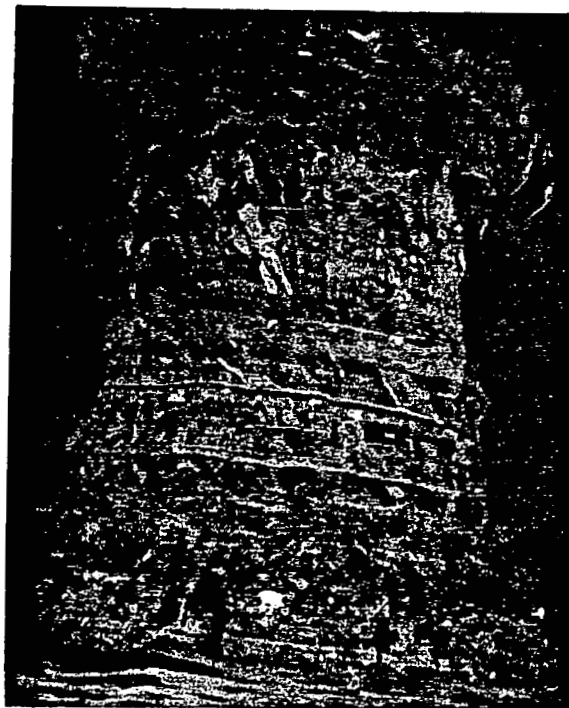


Pillar 3/4 (60'H)

9/17/69



9/17/69



Colony oil shale mine
Pre- and post shot photos

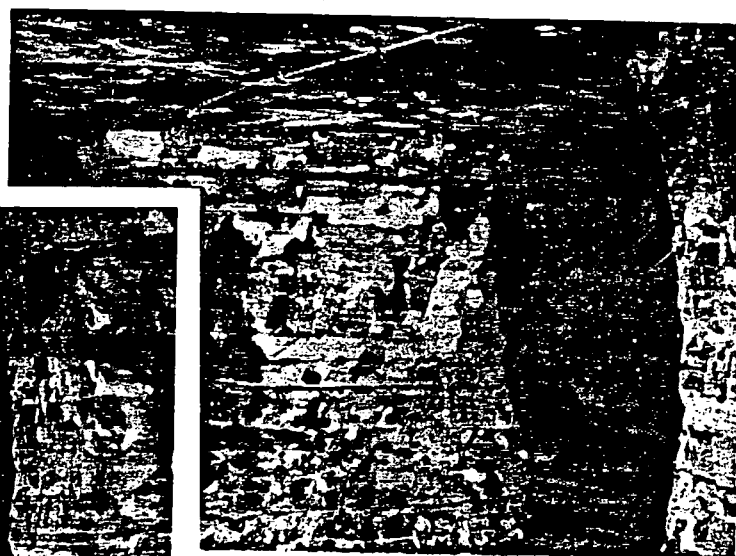
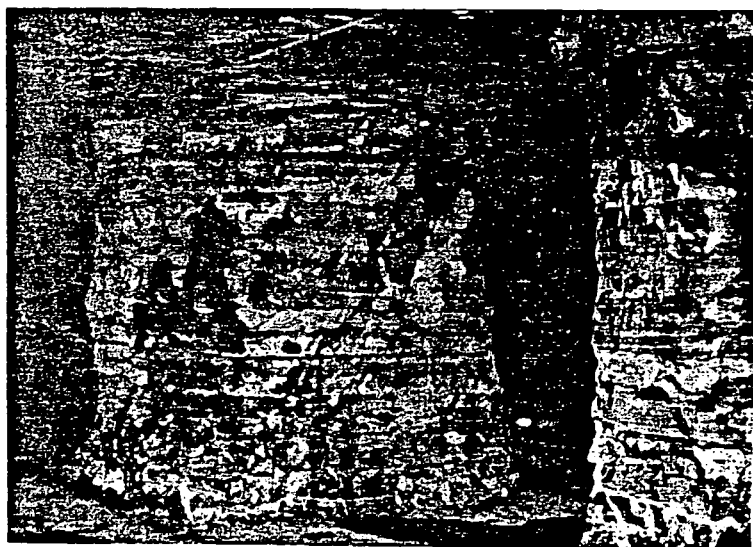
9/17/69



8/21/69

Base Pillar 2/3

9/17/69



8/21/69

Pillar 2/3 (60'H)

8/26/69

Nu-Gap coal mine
Pre- and post-shot photos



8/26/69



9/15/69



9/15/69

Portal of slope entry in steeply-pitching coal seam.



8/26/69

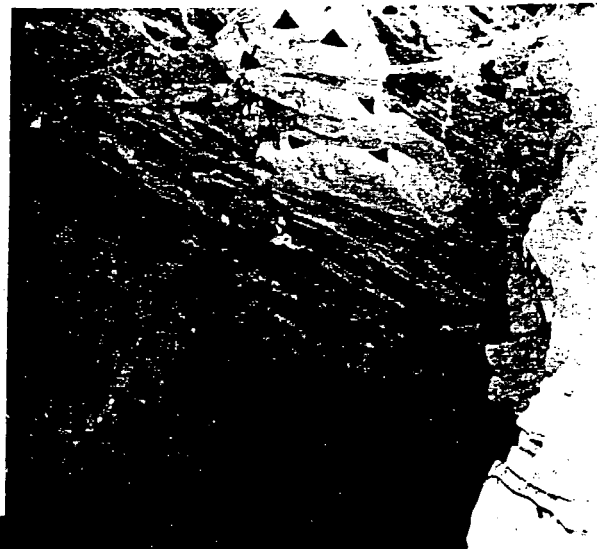


9/16/69

Pillar on A level between
hoist station and inclined shaft



8/26/69



9/16/69

Back and pillar midway down old incline from A level



8/26/69



9/16/69

Fractured sandstone above timber set on A level, outby 54 draw

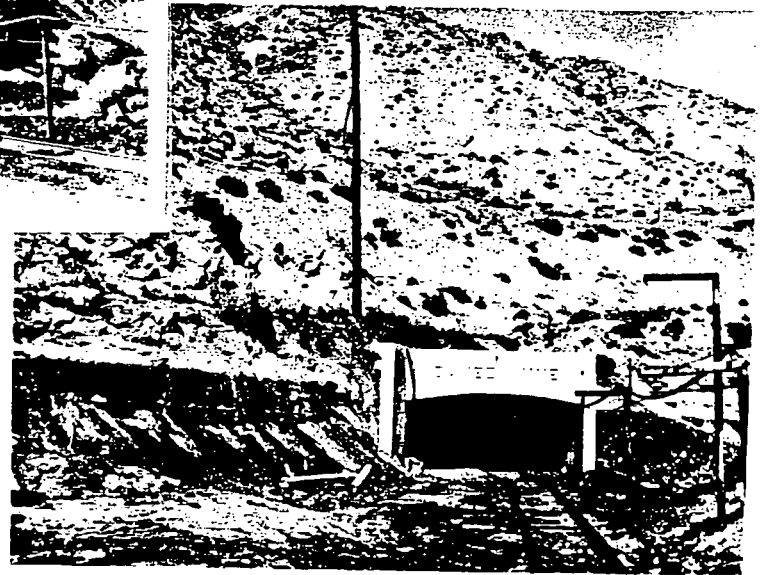
Cameo coal mine
Pre- and post-shot photos



9/3/69

9/11/69

Portal of main haulage
entry



Caved cap rock around
roof bolts in No. 11
room, 2nd East, at
breaker row

Cameo coal mine
Pre- and post-shot photos



Caved roof of 3rd West
haulage entry



Timbers taking weight of
roof sag and floor heave
in 3rd West haulage entry



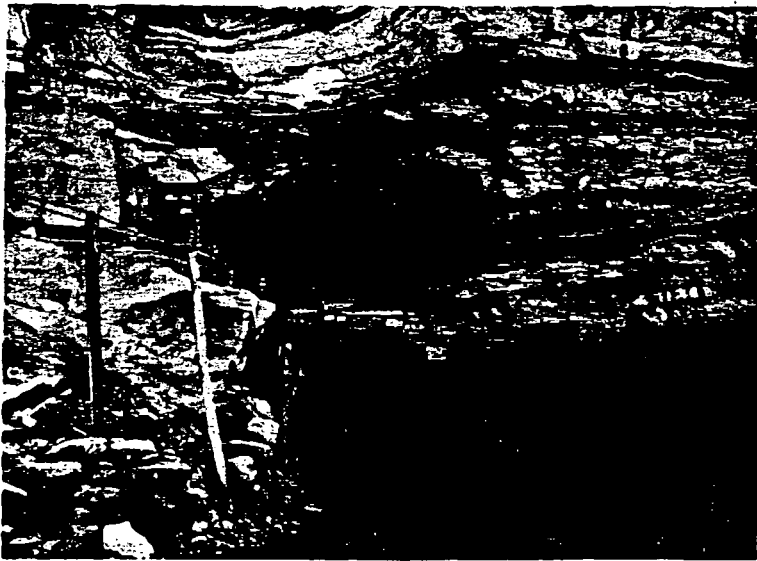


Timber crib in caved section of
surface alluvium in No. 2 Outside entry



Cap rock and top coal separation above
timber supports in No. 1 Southwest entry

Roadside coal mine
Pre- and post-shot photos



8/29/69

9/11/69

Portal and portal timber
sets of main haulage
entry



9/11/69



8/29/69



Topped post and fallen
cap piece in main
haulage entry - 9/11/69



8/29/69



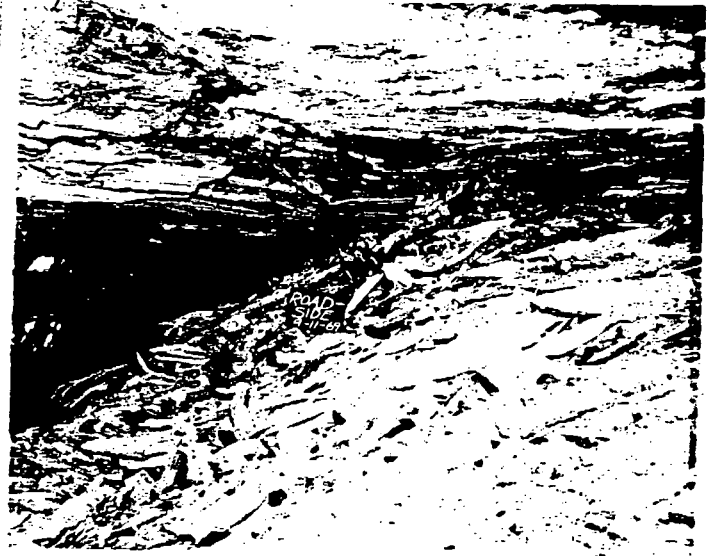
9/11/69

Caved section of main haulage entry

Roadside coal mine
Pre- and post-shot photos



8/29/69



9/11/69

Recently caved material (under sign) in air intake



8/29/69



9/11/69

Portal of return airway and emergency escapeway